6.0 Radiation Dose

Results in Brief: 2003 Estimated Doses

Airborne Emissions — The estimated maximum effective dose equivalent at the site fenceline from 2003 airborne emissions (excluding radon) was calculated to be 0.82 mrem (8.2E-03 mSv), which is 8.2 percent of the EPA NESHAP 10-mrem annual dose limit.

Direct Radiation — The estimated 2003 effective dose equivalent at an off-site receptor location near the western fenceline of the site was 6.7 mrem (6.7E-02 mSv).

Biota (Produce) — The dose for consuming locally grown produce was calculated to 0.003 mrem (3.0E-05 mSv).

Dose to the Maximally Exposed Individual — The dose to the maximally exposed individual for 2003 was estimated to be 7.33 mrem (7.3E-02 mSv) at an off-site receptor location near the western fenceline of the site. This is 7.3 percent of the 100-mrem (1-mSv) DOE limit.

This chapter provides estimated doses to the public from the air, biota (produce), and direct radiation pathways for 2003 as a result of remedial actions taken at the Fernald site. EPA NESHAP regulations require the FCP to demonstrate that the site's radionuclide airborne emissions are low enough to ensure that no one in the public receives an effective dose of 10 millirem (mrem) (0.1 milliSievert [mSv]) or more in any one year. Moreover, to determine whether the Fernald site is within the DOE effective dose limit of 100 mrem (1 mSv) per year from all exposure pathways (excluding radon), estimates of dose due to direct radiation and produce are combined with airborne emissions to estimate the total dose to the maximally exposed individual. This estimate reflects the incremental dose above background that is attributable to the site.

The DOE limits for radon and its decay products in air are provided in terms of concentrations rather than dose limits and are addressed independently of the all-pathway dose limit. A concentration-based limit is used because dose calculations associated with radon and its decay products are highly sensitive to input parameters which are difficult to confirm with environmental measurements. Nevertheless, dose estimates for radon have been included in response to stakeholders' interest in radon exposures. A number of different radon dose calculations are presented to demonstrate the variation of radon doses based on each method of calculation. The radon dose estimates in this chapter can also be compared with radon dose estimates presented in previous annual site environmental reports and other radon dose studies, such as the study that resulted from the Fernald Dosimetry Reconstruction Project (RAC 1996).

This chapter also provides an assessment of dose to aquatic organisms that may be affected by the site's effluent to nearby streams and rivers. An assessment of dose to biota (i.e., aquatic and terrestrial organisms) is one of the requirements of DOE Order 5400.5 (DOE 1990b). By limiting the dose to aquatic organisms, DOE Order 5400.5 seeks to limit the severity and likelihood of off-site environmental impacts attributable to the cleanup and restoration efforts at the Fernald site. The dose assessment to biota is performed through the use of a computer model which estimates dose based on concentrations of radionuclides measured in effluent discharged to the Great Miami River.

6.1 Estimated Dose from Airborne Emissions

The estimated dose from 2003 airborne emissions was calculated from annual average radionuclide concentrations measured at the 17 IEMP air particulate monitoring locations (one background and 16 fenceline locations [refer to Figure 5-1 in Chapter 5 for the location of the air particulate monitoring locations]). The annual average background concentration was subtracted from the fenceline concentrations in order to account for the natural occurrence of airborne radionuclides. Dose estimates were determined by converting the net annual average radionuclide concentrations measured at each fenceline monitoring location to doses using values listed in 40 Code of Federal Regulations 61 (NESHAP) Subpart H, Appendix E, Table 2.

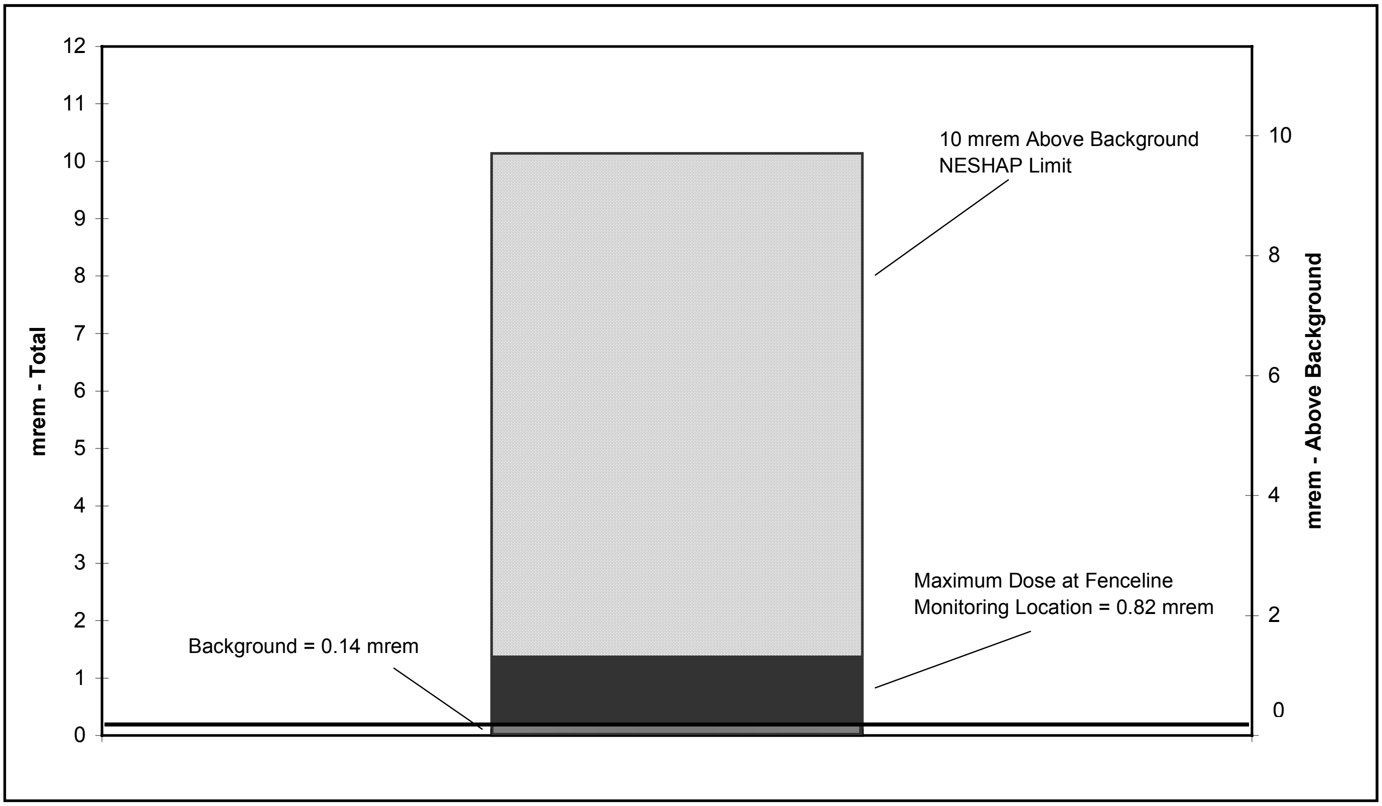


Figure 6-1. Comparison of 2003 Air Pathway Doses and Allowable Limits

The maximum effective dose at the fenceline from 2003 airborne emissions was estimated to be 0.82 mrem (8.2E-03 mSv) per year and occurred at AMS-9C along the eastern fenceline of the site. The dose estimate is based on the conservative assumption that a person remains outdoors at the AMS-9C location for 100 percent of the time during the year. Recognizing that the nearest residence is located approximately 2,500 feet (762 meters) downwind from AMS-9C (east-southeast from the site), the actual dose received by this receptor would be substantially lower than 0.82 mrem (8.2E-03 mSv) per year.

The maximum fenceline dose of 0.82 mrem (8.2E-03 mSv) in 2003 is consistent with the maximum fenceline dose of 0.8 mrem (8.0E-03 mSv) in 2002. The equivalence between the 2002 and 2003 doses is particularly noteworthy given the Waste Pits Project accelerated waste processing activities in 2003. The operation of the PVS, which was designed to capture particulate emissions from waste material processed by the dryers, is credited with limiting Waste Pits Project emissions during accelerated waste processing activities while maintaining the 2003 maximum dose to approximately 0.8 mrem, well below the NESHAP limit.

Figure 6-1 provides a comparison between the air pathway doses at the background and maximum fenceline locations with the annual NESHAP limit of 10 mrem (0.1 mSv). The background and maximum fenceline doses shown in Figure 6-1 are primarily attributable to the airborne concentration of uranium, thorium, and radium, and exclude contributions from radon (dose from radon is excluded from the annual NESHAP limit of 10 mrem [0.1 mSv]). The maximum air pathway dose of 0.82 mrem (8.2E-03 mSv) above background (which is in addition to the air pathway background dose of 0.14 mrem [1.4E-03 mSv]) is 8.2 percent of the annual NESHAP limit. The estimated dose for each radionuclide from airborne emissions measured at each fenceline air monitor is provided in Appendix D of this report.

The collective effective dose from 2003 airborne emissions (not including radon) to the population within 50 miles (80 km) of the Fernald site was estimated to be 3.84 person-rem (3.84E-02 person-Sievert [person-Sv]) for a population of 2.7 million. The collective effective population dose for all pathways (air, direct radiation, and consumption of local produce) was estimated to be 3.99 person-rem (3.99E-02 person-Sv). The collective effective dose provides an aggregate measure of the impact of airborne emissions from the Fernald site to the population in the area. For comparison, the same group of people received an estimated collective effective dose of 300,000 person-rem (3,000 person-Sv) from background radiation, excluding radon.

6.2 Direct Radiation Dose

Direct radiation dose is the result of gamma and X-ray radiation emitted from radionuclides stored on site. The largest source of direct radiation at the site is the waste stored in the K-65 Silos. As the waste in the silos undergoes radioactive decay, gamma rays and X-rays are emitted. Direct radiation from the decay of radon progeny in the silos' headspace contributes a major fraction of the direct radiation from the K-65 Silos.

As discussed in Chapter 5, there was a significant decrease in the radiation levels during 2003, particularly at TLD location 6, which is located closest to the K-65 Silos (refer to Figure 5-9). These changes at the fenceline are also attributable to the reduction of radon concentrations and associated decay products within the K-65 Silos' headspace by the operation of the Silos Project RCS.

The direct radiation dose for 2003 at the fenceline was estimated using the highest dose from the fenceline monitoring locations and subtracting the background dose. This method provides a conservative estimate of direct radiation dose and measures the impact of radiation levels near the silos and the fenceline due to radon and its associated decay products in the silo headspace (refer to Chapter 5). From the data in Table 5-3, the maximum fenceline measurement was 76 mrem (7.6E-01 mSv) per year and occurred at TLD location 16. The average background dose from the five background TLD locations was 65.6 mrem (6.56E-01 mSv). The difference in these values (10.4 mrem [1.04E-01 mSv]) is the estimated fenceline direct radiation dose for a hypothetical individual who stands at the fenceline, specifically TLD location 16, for the entire year.

In accordance with DOE Order 5400.5, which requires that realistic exposure conditions be used for conducting dose evaluations, an estimate of direct radiation dose was calculated for the residence nearest the K-65 Silos. This dose was estimated by using the net fenceline TLD measurement at TLD location 16 and accounting for the distance between the fenceline TLD location and the residence (approximately 326 feet [99 meters]), which would lower the direct radiation dose to approximately 6.7 mrem (6.7E-02 mSv). This estimate remains extremely conservative in that it assumes a resident at this location is present 24 hours per day for a full year and does not account for shielding provided by the structure of the house.

6.3 Estimated Dose from Consumption of Locally Grown Produce

There is a potential for low levels of radioactive particulate emissions to be deposited onto soil surrounding the FCP and possibly absorbed by produce, thereby delivering a secondary pathway dose. This secondary pathway dose is estimated using the conservative assumption that a large fraction of a person's diet of vegetables comes from gardens and farms in the FCP area. This modeled diet assumes an annual consumption of 100 pounds (45 kg) of grains (corn and soybeans), and 100 pounds (45 kg) of other vegetables (tomatoes and cucumbers). To represent the foods in the diet, samples of corn, soybeans, tomatoes, and cucumbers from local gardens and farms were collected and analyzed in 2003 for uranium and thorium-230.

Historically, produce sampling at the FCP consisted of uranium analysis. During the 2000 sampling year, isotopes of thorium and radium-226 were included in the analyses. Thorium analysis was included because thorium-230 became the major contributor to dose from airborne emissions during the last four years. Radium analysis was included as a response to a study conducted by the Agency for Toxic Substance and Disease Registry (ATSDR 2000), which suggested that radium may be a potential contributor to dose based on the ATSDR's review of historical environmental data. Of the samples analyzed in 2000, only total uranium and thorium-230 analyses yielded detectable results. Therefore, the 2003 produce samples were analyzed for total uranium and thorium-230 per the IEMP.

For 2003 the estimated dose from consuming locally grown produce was calculated to be 0.003 mrem (3.0E-5 mSv). For comparison, the 2000 dose was calculated to be 0.9 mrem (9.0E-03 mSv). As indicated in Chapter 5, produce samples had very low concentrations of thorium-230 (i.e., 0.04 to 0.48 pCi/g) while most uranium concentrations were not detectable. More details on produce samples are provided in Appendix C.4 of this report.

6.4 Total of Doses to Maximally Exposed Individual

The maximally exposed individual is the member of the public who receives the highest estimated effective dose equivalent based on the sum of the individual pathway doses. As shown in Table 6-1, the 2003 dose to the maximally exposed individual is the sum of the estimated doses from direct radiation dose, airborne emissions (excluding radon), and consumption of locally grown produce. The conservative assumptions used throughout the dose calculation process ensure that the dose to the maximally exposed individual is the maximum possible dose any member of the public could receive. The 2003 dose to the maximally exposed individual is estimated to be 7.33 mrem (7.33E-02 mSv).

The contributions to this all-pathway dose are:

- 6.7 mrem (6.7E-02 mSv) from direct radiation to an off-site receptor located near the western fenceline of the site
- 0.63 mrem (6.3E-03 mSv) from air inhalation dose, as measured at AMS-6, to an off-site receptor located near the western fenceline of the site
- 0.003 mrem (3.0E-05 mSv) biota (produce) dose from consuming locally grown produce.

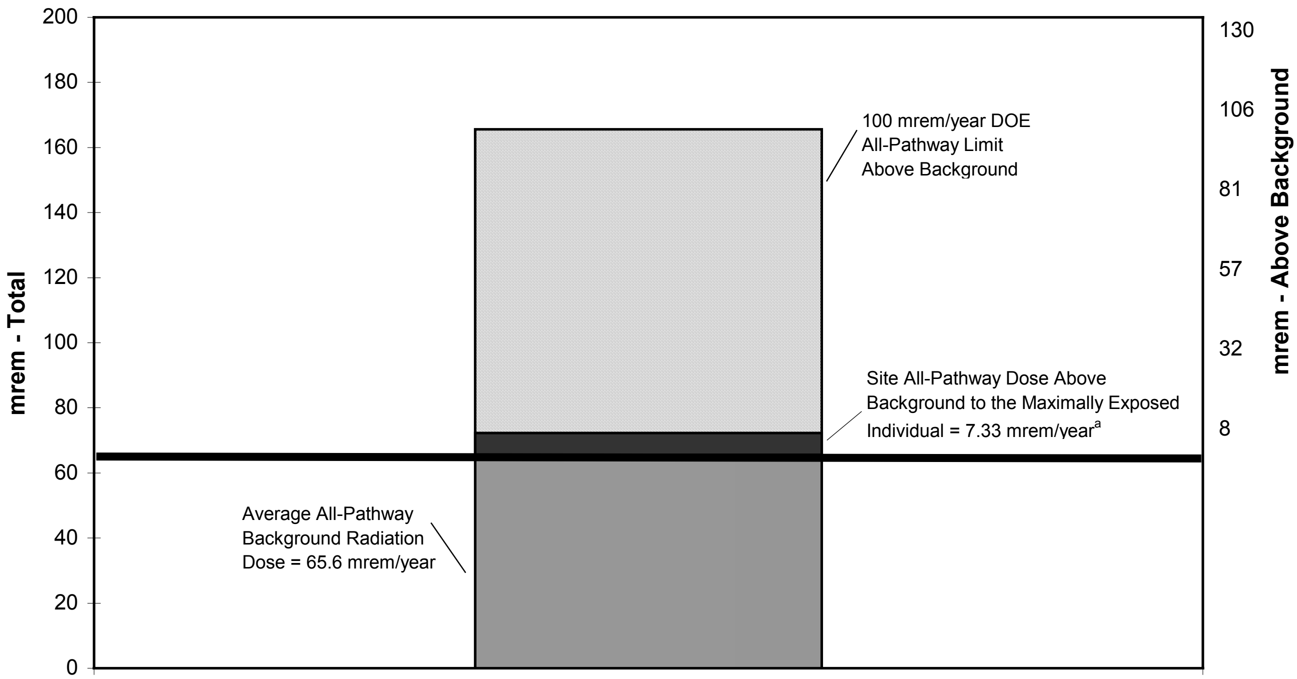
This estimate represents the incremental dose above background attributable to the Fernald site, exclusive of the dose received from radon. Figure 6-2 provides a comparison between the average background radiation dose at background locations (65.6 mrem [6.56E-01 mSv]) and the all-pathway dose to the maximally exposed individual (7.33 mrem [7.33E-02 mSv]). Figure 6-2 also provides a graphical comparison to the annual DOE all-pathway limit of 100 mrem (1 mSv).

TABLE 6-1
DOSE TO MAXIMALLY EXPOSED INDIVIDUAL

Pathway	Dose Attributable to the Fernald Site	Applicable Limit
Direct radiation	6.7 mrem	100 mrem (total of all pathways)
Airborne emissions at AMS-6 (excluding radon)	0.63 mrem	10 mrem (air pathway)
Consumption of locally grown produce	0.003 mrem	100 mrem (total of all pathways)
Maximally exposed individual	7.33 mrem	100 mrem (total of all pathways)

6.5 Significance of Estimated Radiation Doses for 2003

One method of evaluating the significance of the estimated doses is to compare them with doses received from background radiation. Background radiation yields approximately 100 mrem (1 mSv) per year from natural sources, excluding radon. For example, the dose received each year from cosmic and terrestrial background radiation contributes approximately 26 mrem (2.6E-01 mSv) and 28 mrem (2.8E-01 mSv), respectively. In addition, the background radiation dose will vary in different parts of the country. Living in the Cincinnati area contributes an annual dose of approximately 110 mrem (1.1 mSv), whereas living in the Denver area would contribute approximately 125 mrem (1.25 mSv) from background radiation (U.S. National Academy of Science 1980) (NCRP 1987). Comparing the maximally exposed individual dose to the background dose demonstrates that, even with the conservative estimates, the dose to the nearest resident from the Fernald site is much less than the natural background radiation dose. Although the estimated dose will be received in addition to the background dose, this comparison provides a basis for evaluating the significance of the estimated doses.



[a] Includes dose from air particulate (0.63), direct radiation (6.7), and consumption of local produce (0.003).

Figure 6-2. Comparison of 2003 All-Pathway Doses and Allowable Limits

Another method of determining the significance of the estimated doses is to compare them with dose limits developed to protect the public. The International Commission on Radiological Protection (ICRP) has recommended that members of the public receive no more than 100 mrem (1 mSv) per year above background. As a result of this recommendation, DOE has incorporated 100 mrem (1 mSv) per year above background as the limit in DOE Order 5400.5. The sum of all estimated doses from site operations for 2003 (7.33 mrem [7.33E-02 mSv]) was significantly below this limit.

6.6 Estimated Dose from Radon

Radon in the air decays to produce more radioactive material, known as daughter products. Airborne daughter products attach to dust particles that may be inhaled and deposited within the lungs. As the daughter products decay, they emit electrostatically charged particles (alpha and beta particles) that may damage sensitive tissues of the lung. For exposures to radon and its daughters, the target organ for the radiation dose is the lung.

Radon dose estimate methodologies from the ICRP and National Council on Radiation Protection (NCRP) have been revised and updated over the years with the primary effect being a decrease in the estimated health damage (detriment) per unit of radiation exposure. The revisions were based on re-evaluations of studies examining the detrimental health effects (e.g., epidemiological studies) on highly exposed worker populations (e.g., uranium miners). Therefore, radon dose estimates were generated for this report using the following four different calculation methods:

- Working level-month determination

  Historically, radon daughter exposure rates have been measured in the units of working levels, a measure of the activity concentration of the radon daughters in air. A working level is approximately equivalent to a radioactivity concentration of 100 pCi/L of radon in 100 percent equilibrium with its daughters. An individual exposure is then determined by multiplying the working level by the number of 170-hour periods (i.e., a work month) at that level, yielding the exposure unit working level-month. Working level-months of exposure are provided because all dose conversion factors and detriment coefficients used in estimating a dose from radon and its daughters are derived from this fundamental unit.

- NCRP 78 report (NCRP 1984)

  This document, in part, provides equations for converting exposure resulting from inhalation of radon daughter products to an equivalent lung dose. This method considered the whole lung as the target organ for the radiation exposure. A number of dose conversion factors and assumptions are used to equate the lung dose to a whole body radiation dose (i.e., effective dose equivalent). Equations from this report were used in previous annual site environmental reports and are presented here for direct comparison to previous years' estimates.

- ICRP 66 (ICRP 1994a) tissue weighting factor modification to NCRP 78 equation

  ICRP 66 introduced a specific tissue-weighting factor representing the localized radiation exposure to the bronchial epithelium (a specific region of the lung thought to be the source for lung cancer) from inhalation of radon daughter products. Using the NCRP 78 equations, this new weighting factor results in a reduction of the effective dose by a factor of three. Incorporation of factors from this report allows comparison to dose estimates provided in the Fernald Dosimetry Reconstruction Project performed by Radiological Assessments Corporation under contract with the Centers for Disease Control.

- ICRP 65 report (ICRP 1994b)

  This report suggests the use of detriment coefficients for estimating dose from exposure to radon daughter products. These detriment coefficients are based on epidemiological studies of the lung cancer rates among uranium miners. The new coefficients result in a dose conversion factor of approximately 500 mrem per working level-month. This report was released in 1994 and represents a more recent methodology for calculating radon dose.

Table 6-2 presents the 2003 radon dose estimates, and includes concentration values for fenceline and background locations as well as DOE radon concentration limit values. Estimated working level-month exposures are given for each concentration value, as well as effective dose equivalents using the NCRP 78, ICRP 66, and ICRP 65 methods. Doses were calculated from annual average continuous radon data (assuming the suggested environmental radon daughter product equilibrium concentration of 70 percent). All dose estimates are for a hypothetical maximally exposed reference man of average body size and breathing rate who continuously breathed air at the site's fenceline while engaged in light, physical activity 24 hours a day for the entire year. This exposure scenario is highly conservative, but suggests that in using the ICRP 65 methodology the dose from radon emissions at the fenceline monitor nearest a public receptor is 18 mrem (0.18 mSv) per year above background.

Although there are no regulatory limits for dose from radon and its daughters, the radon concentration limits imposed by DOE Order 5400.5 provide a benchmark for evaluating the estimated doses from radon at the Fernald site boundary. In DOE Order 5400.5, the annual average radon concentration limit at the facility boundary is 3 pCi/L above background. Using the ICRP 65 methodology, a concentration of 3 pCi/L equates to an effective dose equivalent of 547 mrem (5.48 mSv). As presented in Table 6-2, the maximum measured radon concentration and corresponding dose at the Fernald site boundary are well below the limits associated with DOE Order 5400.5.

TABLE 6-2
2003 RADON DOSE ESTIMATE[a]

Location	Radon Concentration (pCi/L)	Exposure in Working Level-Months	NCRP 78 Effective Dose Equivalent Equation		ICRP 65 Effective Dose Equivalent (mrem)[d]
			(mrem)[b]	(mrem)[c]	
Background	0.3	0.108	216	72	55
FCP Fenceline Nearest Receptor (net, above background)	0.1	0.036	72	24	18
Maximum Fenceline (net, above background)	0.3	0.108	216	72	55
DOE Order 5400.5 Limit (net, above background)	3.0	1.08	2,160	720	547

[a]Assuming the suggested environmental radon daughter product equilibrium concentration of 70 percent.
[b]NCRP 78 suggests whole lung tissue weighting factor of 0.12.
[c]NCRP 78 calculation using the ICRP 66 bronchial epithelium weighting factor of 0.04.
[d]Using the dose conversion factor for the maximally exposed reference man.

6.7 Estimated Dose to Biota

DOE Order 5400.5 requires that populations of aquatic biota be protected at a dose limit of 1 rad/day (10 milliGray per day [mGy/day]). The DOE has issued a technical standard entitled, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE 2002b) and supporting software (RAD-BCG) for use in the evaluating and reporting of compliance with biota dose limits.

In general, the dose and compliance assessment process involves comparing concentrations of contaminants measured in surface water and sediment samples to established Biota Concentration Guides (BCGs) for specific radionuclides. More specifically, the measured contaminant concentration in water and/or sediment is divided by the appropriate BCG value. If the resulting fraction is less than 1.0, compliance with the biota dose limit is assured. The BCGs were set so that real biota exposed to such concentrations would not be expected to exceed the biota dose limit of 1 rad/day (10 mGy/day) during a calendar year. BCGs have been established for a set of radionuclides that are relatively common constituents in past radionuclide releases to the environment from DOE facilities. At facilities such as Fernald, where multiple contaminants (e.g., uranium, radium, and thorium) can be released, a "sum of the fractions" rule applies. Compliance with the biota dose limit is assured if the sum of the fractions from multiple contaminants is less than 1.0.

For 2003 compliance with the dose limit to aquatic biota was determined by using the maximum concentrations of applicable radionuclides found in effluent discharged to the Great Miami River (refer to Chapter 4) as input into the RAD-BCG computer model. The results of the assessment indicate that the sum of the fractions was 0.035, which is well below the compliance threshold value of 1.0.

Detailed data and information on evaluating compliance with the biota dose limits for 2003 and previous years are provided in Appendix C, Attachment C.6, of this report.

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